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(71) Applicant(s)
Monitoring Systems Limited

(Incorporated in the United Kingdom)

Commerce House, Commerce Way, EDENBRIDGE, Kent, TN8 6ED, United Kingdom

(72) Inventor(s)
Peter John Bellingham
Tony David Thompson
Stephen Edwin Marks

(74) Agent and/or Address for Service
Urquhart-Dykes & Lord
91 Wimpole Street, LONDON, W1M 8AH, United Kingdom

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(56) Documents Cited
EP 0243011 A1 WO 91/08492 A1 US 4536967 A
US 4503622 A

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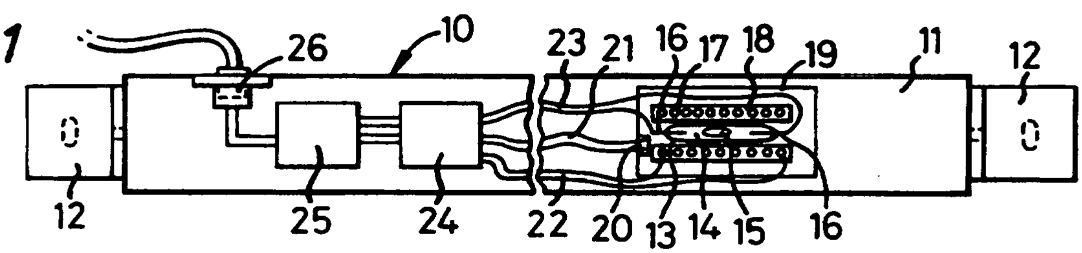
(54) **Electronic spirit level**

(57) A mounting beam 11 supports a closed vial 13 charged with a liquid electrolyte 14 and a gas bubble 15. Spaced electrodes 16 are exposed to the fluid to provide an electrical signal representative of the angle of the vial. A heating element 17 surrounds the vial, and control means 24 controls the heating element to tend to maintain the vial at a predetermined elevated temperature rather higher than normal ambient temperature. A microprocessor 24 includes a look-up table of pairs of test angles and test vial voltage signals pre-calibrated on manufacture so as to provide in use an output signal linearly representative of the angle of the electrolevel.

FIG.1



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The claims were filed later than the filing date within the period prescribed by Rule 25(1) of the Patents Rules 1995

FIG.1

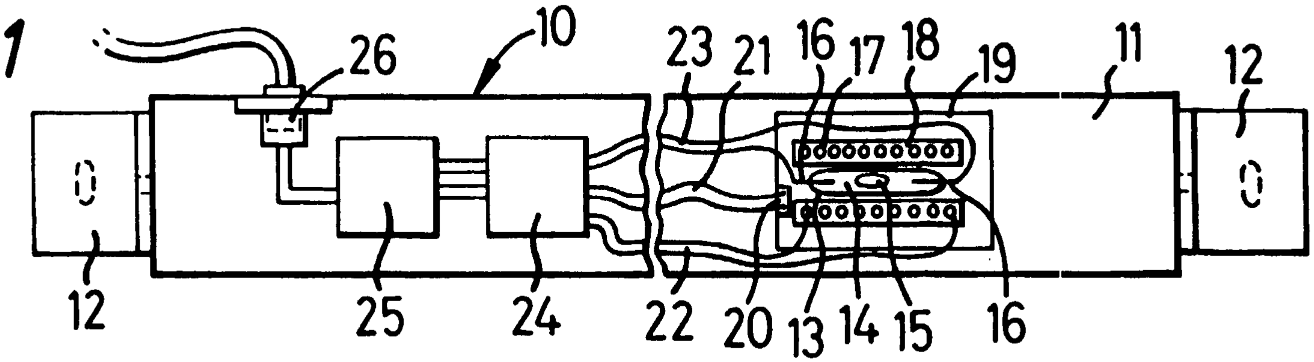
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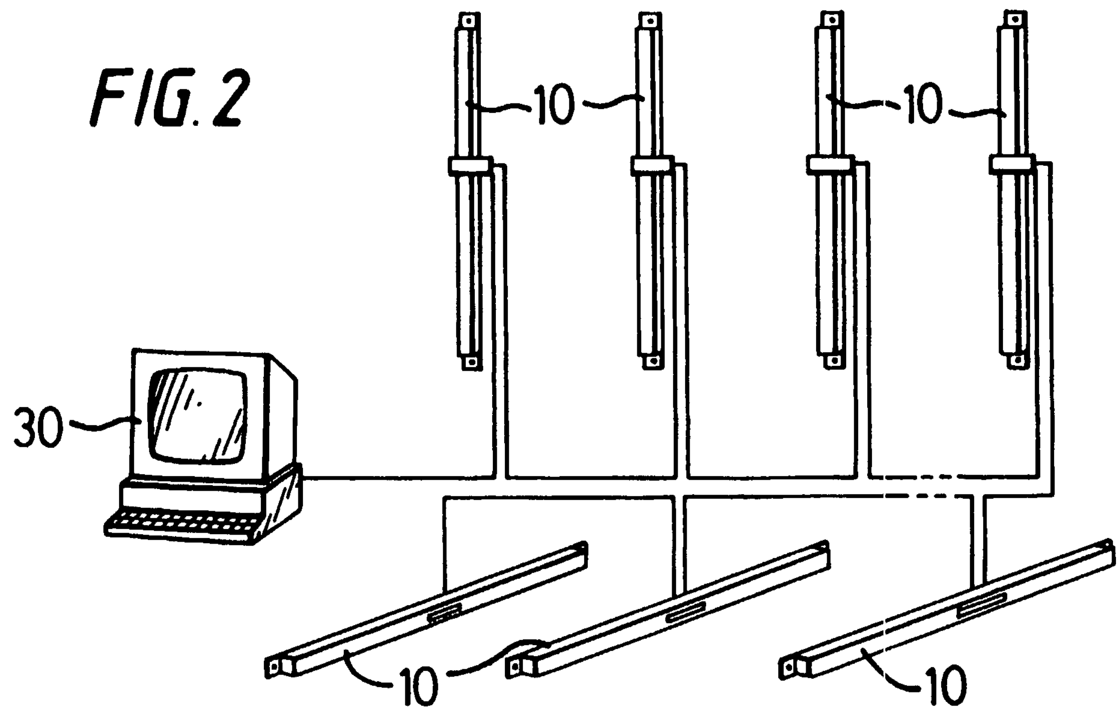
FIG.2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IMPROVEMENTS RELATING TO ELECTROLEVELS

This invention relates to electrolevels, i.e. spirit levels with electrical signal read-out.

A typical electrolevel comprises a sealed glass vial containing a liquid electrolyte and a gas bubble. The vial is supported by an elongate mounting element and usually has a nominal zero angle, i.e. horizontal, parallel to or perpendicular to the length of the mounting element for detecting horizontal or vertical orientations.

Spaced electrodes are exposed to the vial fluid and in use a voltage is applied across the electrodes. The vial thereby behaves as an impedance whose magnitude varies with the angle of the mounting element over a predetermined range. The vial can be connected in an AC impedance bridge circuit to provide a positive or negative voltage read-out whose sign indicates a clockwise or anti-clockwise tilt of the electrolevel and whose magnitude is representative of the angle.

Glass vials have been manufactured for many years and the technology is well established. A wide variety is available with predetermined angular ranges of from 1 to 360°, the accuracy normally being inversely proportional to the range. A typical 1° vial can be accurate to within one second of arc, while a 360° vial can resolve only to several minutes of arc. The range is primarily determined by the shape of the vial, from a complete hollow torus to a short straight or slightly curved tube. Each vial is manufactured mainly by hand. A non-uniform, asymmetric, irregular, or poorly sealed shape could render the vial unusable. The charge and formulation of the electrolyte and gas must also be precise as must be the placement of the electrodes. Rigorous inspection and testing is necessary at each stage.

Even with such great care, it is known that each vial is essentially unique and therefore each assembled

electrolevel instrument requires individual calibration. A typical electrolevel might have a reasonably linear relationship between output voltage and angle over the central portion of its range around nominal zero, i.e. horizontal, but the relationship can become significantly non-linear away from the central range. For example, a 10 mV reading may represent 20 seconds of arc, 20 mV may represent 40 seconds of arc, but 25 mV may represent 60 seconds of arc.

Accordingly, each electrolevel is pre-calibrated in the factory and provided with an individual graph or table of calibration data to permit correction of actual output voltages into corrected angles. Typically, a complete non-linear correction is simplified to approximate straight line corrections, thereby slightly simplifying use at the expense of potential accuracy in the indicated angle.

An important use of electrolevels lies in geotechnical measurements of building and civil engineering structures and earth movements. Large numbers of electrolevels can be connected in one or more networks or arrays on a substantial site such as a large building, a bridge or a tunnel. Such a site can extend for several kilometres and may require upto several hundred electrolevels for proper sensing and monitoring of the levels, both horizontal and vertical, in the structures.

Moreover, it may be required to provide electrolevels in relatively inaccessible positions such as the undersides of bridge decks or along railway tunnel walls or on deep vertical piles.

A serious problem in the prior art lies in this combination of the need for an individual set of calibration data to be associated with each electrolevel together with the presence of a large number of electrolevels on a building site. Building sites are

crowded with heavy moving equipment and materials, and instrumentation and cabling is prone to physical damage.

Where an array of electrolevels each have a voltage read-out signal lead running to a data logger on site, there will be an equally large number of individual cables upto a practical limit of about 200 metres in length. Because the electrolevels require individual calibration, it is essential that each cable terminal at the data logger is identified with its individual electrolevel. If the cabling is physically damaged on site, it can therefore be difficult if not impossible to re-connect the correct cables to each electrolevel, especially where some electrolevels are currently inaccessible for identification.

Furthermore, each electrolevel is not only individually calibrated in itself, but requires to be calibrated with the actual cable used to connect that electrolevel to the data logger. A different cable length will have a different electrical impedance, may run between areas of differing temperature, and may be prone to magnetic effects when run close to power cables or powerful radio frequency sources. Thus each cable must be coded and correctly run to its electrolevel or the eventual angle read-outs may be useless.

It is also known that environmental temperature variations affect the readings of electrolevels, typically again in a non-linear manner. The vial itself is normally of glass, thereby having a low coefficient of thermal expansion. However the vial mounts can expand and contract with temperature variation, and the precise constitution and proportion of the gaseous and liquid phases within the vial is also subject to complex change with temperature variation. It is now found that the variations due to the vial itself are non-linear both with temperature and with angle, and that accordingly certain vials are only capable of their notional accuracy, even

after corrections, when nearly level and at a temperature near the temperature at which they were calibrated in the factory.

Typically, the elongate supports for the vials are constructed in a symmetrical manner to tend to reduce heating and cooling effects, and the vials are usually calibrated in the factory at a standard temperature of 20°C. A temperature sensor can be mounted on each electrolevel to provide a reading of actual local environmental temperature when the electrolevel is in use. The ambient temperature to which an electrolevel is exposed can vary substantially on certain building sites, for example between damp tunnels or footings and metal super-structures exposed to sunlight, and the diurnal variation can be significant. Those actual temperature readings can be transmitted by cables to the data logger.

Accordingly, it is recognized that a substantial quantity of raw data can be provided by an array of electrolevels to a data logger. Detailed calibration look-up tables, charts or graphs can then be applied to each tilt angle voltage reading and temperature reading from each electrolevel along its individual cable to correct the readings eventually to provide a set of angle data for the building structure in the region of each electrolevel where that electrolevel is secured by its mounting beam to the structure. In principle, the calibration look-up tables can be stored on computer on site at the data logger location. An accuracy of less than 1 second of arc can be derived from 3° vials in this manner, representing down to sub-millimetric absolute movements in the building structures or earth formations being monitored.

These procedures require extreme care by skilled personnel. The proper accumulation of the raw data and its subsequent correction and interpretation is subject to all the above-described difficulties. In practice, it has

been found that the data is either incorrectly accumulated or incorrectly calibrated or incorrectly interpreted, or the raw data is simply allowed to accumulate for days before the relevant computer and/or skilled person is available on or off site to process and interpret the data. This can negate the entire point of sensitive and accurate monitoring of angle movements of seconds of arc or sub-millimetric absolute movements in building structures where such small changes can give advance warning of problems, for example when driving tunnels between or closely adjacent to the foundations of existing buildings. Diurnal variations of angle or absolute movement might be required to be monitored on an hourly basis to obtain meaningful results, and a consistent trend of day-to-day accumulating tilt or absolute movement should be noticed promptly, rather than after the problem has occurred. For example, the collapse of an entire building can be averted if the angle data actually available from an array of electrolevels could be obtained in a manner both accurate and immediate.

An object of the present invention is to make it possible to provide such improved electrolevels and electrolevel arrays.

According to the present invention there is provided an electrolevel comprising a mounting element supporting a closed vial charged with fluid consisting of a liquid electrolyte and a gas bubble, spaced electrodes electrically exposed to said fluid to provide an electrical signal representative of the angle of said vial over a predetermined range, heating means to apply heat to said vial, and control means operable to control said heating means to tend to maintain said vial at a predetermined elevated temperature.

The predetermined elevated temperature is suitably about 40°C, i.e. rather higher than normal ambient temperature.

The heating means is suitably an electrical heating filament which may be counter-wound in two coils of opposite winding sense to minimize electromagnetic effects. The heating current may be controlled to be simply on or off, or be variable, or be pulsed with a variable duty cycle. The control means includes a temperature sensor positioned to sense the actual temperature closely adjacent to the vial, and a comparator circuit to compare the sensed temperature with the desired temperature, to permit the control means to control the current flow in the heating filament to tend to maintain the vial quite closely at 40°C. A power source, such as a 12 volt rechargeable battery, may supply power both to the heating means and to the electrolevel circuitry, and may be a remote source supplying a plurality of electrolevels.

The vial itself has little thermal mass and is traditionally fairly exposed for visual inspection. In order to assist temperature stability, the vial is preferably mounted to a body providing thermal mass and largely or wholly surrounded with thermal insulation material. The heating element coil can be arranged within or on the inner surface of the surrounding thermal mass.

Vials are traditionally manufactured of glass which has a small coefficient of thermal expansion. Certain ceramic materials have an even lower coefficient, but present comparable difficulties in manufacture. The aim is to manufacture vials with identical internal volume, for reproducibility, but the volume inevitably varies to some extent when the vial is closed after charging with a predetermined metered quantity of electrolyte liquid. The charging opening is at one end since it would inevitably have a distorted non-linear effect on the bubble if provided centrally of the vial. An advantage of certain ceramics over glass is that is can be less difficult to provide the electrodes, e.g. of platinum, by a printing

process on and through the vial wall. The heating element conductor can then also be printed on the vial itself.

Each electrolevel is preferably provided with an individual microprocessor connected to receive the electrical signal from the vial electrodes. The completed electrolevel is heated and stabilized at the predetermined temperature, e.g. 40°C, in the factory and moved through its full range of angles while the on-board microprocessor stores each pair of externally known angles and vial voltage signals in a look-up table format.

It will be appreciated that the resultant electrolevel, when installed on site to a building structure and stabilized at its predetermined temperature, provides an output signal directly and linearly representative of the angle of that electrolevel and throughout the measuring range of the vial. That output signal from the microprocessor is preferably a digital signal.

It will further be appreciated that each such digital signal can be associated with an address or number indicative of that electrolevel position. Such signals are then independent of any particular cabling, data logger or computer requirements. It is no longer necessary to provide 150 separate individually calibrated cables where an array of 150 electrolevels is in use. Instead, with an array of electrolevels according to the invention, the digital signals from each of an array of electrolevels can be read-out in sequence on interrogation along a single digital signal cable. At the read-out computer, no further individual signal correction is required, since each electrolevel is providing a signal directly and linearly representative of the angle of that electrolevel.

The angle signals are therefore accurate and available in real-time and can be monitored in real-time by relatively un-skilled personnel unfamiliar with any

calibration or correction requirements. The angle measurements thereby acquire significant utility for real-time monitoring of building structure and earth formation movement.

Since each electrolevel microprocessor is providing a direct signal linearly representative of angle, it can alternatively be read by a building surveyor moving around the array with a relatively simple hand-held display unit or portable computer.

In the event of physical damage to the array, only a single cable requires replacement. If any one or more of the electrolevels themselves cease to function, the remainder of the array continues to function, and the faulty electrolevel can be replaced with a simple plug connection. No further re-wiring or re-calibration is required. The integrity of the angle data is retained independent of the length of the signal cable and is independent of environmental temperature changes.

With an effective real-time movement monitoring system for a building structure provided by an electrolevel array according to the invention, it becomes possible to pre-set trigger levels for maximum permitted angle or absolute movement changes, with automatic local or remote alarm signal generation in the event that a trigger level is exceeded.

Such an electrolevel network may have a site vibration sensor associated therewith. An on-site pile driver, or a movement of a train over a bridge, can create a temporary peak angle or absolute movement change. That can be sensed by the vibration sensor as a temporary phenomenon, and dis-able the electrolevel readings for a limited short period while the vibratory movement is at a maximum. False alarms can thereby be avoided.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of an electrolevel according to the invention; and

Figure 2 is a schematic diagram of an array of electrolevels according to the invention.

Figure 1 shows an electrolevel 10 comprising an elongate rigid mounting beam 11 with adjustable fixing brackets 12 at each end. These enable the electrolevel to be secured in a precise horizontal or vertical position to a building structure.

A closed glass vial 13 is charged with a liquid electrolyte 14 and a gas bubble 15. Spaced electrodes 16 are exposed to the fluid to provide an electrical signal representative of the angle of the vial over its predetermined design range.

An electrical heating filament 17 is counter-wound in two coils of opposite winding sense around the vial. The vial and heating means is housed in a body 18 providing thermal mass and are largely surrounded with thermal insulation material 19.

A temperature sensor 20 is positioned to sense the actual temperature closely adjacent to the vial. Leads 21 provide an electrical signal representative of the sensed temperature.

Leads 22 provide a low voltage DC heating current to the heating filament. Leads 23 effectively connect the variable impedance presented by the vial in an AC electrical impedance bridge circuit.

The leads 21, 22 and 23 extend to a microprocessor 24, in turn connected to a rechargeable DC voltage power supply 25 and to a signal read-out port 26.

The microprocessor 24 effectively provides the AC electrical impedance bridge circuit to generate the raw data voltage signal non-linearly representative of the angle of the vial. The microprocessor further embodies control means including a comparator circuit to compare the sensed temperature from sensor 20 with a desired

temperature and operable thereby to control the current supply to the heating filament 17 to tend to maintain the vial at a predetermined elevated temperature.

The predetermined elevated temperature is preferably 40°C, i.e. rather higher than normal ambient temperature.

The microprocessor 24 further includes a correction memory. On completion of manufacture of an electrolevel, it is heated and stabilized at the predetermined temperature, e.g. 40°C, in the factory. The electrolevel is then tilted gradually through its full range of angles in appropriate steps, e.g. a fraction of one second of arc, while the microprocessor 24 is gated to store each pair of externally known angles and vial voltage signals in a look-up table format. The measuring range of the complete calibrated electrolevel is thereby of improved accuracy and moreover the accuracy extends to the limits of the angular range of each type of vial. A 1° electrolevel is thereby usable throughout the 1° range with consistent high level accuracy.

The signal output port 26 may be a standard RS-232 data interface in simple cases, or preferably an RS-485 standard data interface when the electrolevel is to be utilized in an extensive array.

Figure 2 is a schematic illustration of a typical array of electrolevels 10 as shown in Figure 1. It will be appreciated that only a single cable connection is required to a site computer 30, the plurality of electrolevels being linked in daisy-chain fashion. The abilities and advantages of such an array have been described above.

CLAIMS:

1. An electrolevel comprising a mounting element supporting a closed vial charged with fluid consisting of a liquid electrolyte and a gas bubble, spaced electrodes electrically exposed to said fluid to provide an electrical signal representative of the angle of said vial over a predetermined range, heating means to apply heat to said vial, and control means operable to control said heating means to tend to maintain said vial at a predetermined elevated temperature.

2. An electrolevel according to Claim 1 wherein said predetermined elevated temperature is substantially 40°C.

3. An electrolevel according to Claim 1 or Claim 2 wherein said heating means is an electrical heating element.

4. An electrolevel according to Claim 3 wherein said electrical heating element is a filament counter-wound in first and second coils of opposite winding sense.

5. An electrolevel according to any one of Claims 1 to 4 wherein the vial is formed of ceramic material.

6. An electrolevel according to any one of Claims 1 to 5 wherein the control means includes a temperature sensor positioned to sense the actual temperature adjacent the vial, and a comparator circuit to compare the sensed temperature with the desired temperature.

7. An electrolevel according to any one of Claims 1 to 6 wherein the vial is mounted to a body providing thermal

mass, said body being substantially surrounded with thermal insulation material.

8. An electrolevel according to Claim 7 wherein said heating means is an electrical heating element arranged within said thermal mass.

9. An electrolevel according to any one of Claims 1 to 8 provided with a microprocessor connected to receive the electrical signal from the vial electrodes, said microprocessor including a memory storing a look-up table of pairs of test angles and test vial voltage signals pre-calibrated against one another.

10. An electrolevel according to Claim 9 wherein said microprocessor is adapted to correct said received electrical signal in accordance with said look-up table to provide an output signal substantially directly and substantially linearly representative of the angle of the electrolevel.

11. An electrolevel substantially as described herein with reference to Figure 1 of the accompanying drawings.

12. An array of electrolevels each according to Claim 10 or Claim 11, said electrolevels being linked in daisy chain fashion by a digital signal cable to a computer operable to read out said output signals from said electrolevels in a desired sequence.

The Patent Office

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Application No: GB 9426105.4
Claims searched: all

Examiner: Michael Walker
Date of search: 12 March 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1F; G1N(part A)(ACNI)

Int Cl (Ed.6): G01C 9/06, 9/24

Other: On-line: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	EP 0243011 A3	(DURACELL) p.4,ll.24 etc	1,5
Y	WO 91/08492 A1	(ZEIGENBEIN) see abstract, at least	1,3,5
Y	US 4536967	(BEITZER) col.3,ll.19-52	1,3,5,7
Y	US 4503622	(SWARTZ) col.2,l.26 to col.3,l.21	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		